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Contractor Report ARFSD-CR-90007

CAST DUCTILE IRON 155 mm M804 BODIES

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This report describes the foundry process for the production of the cast ductile iron 155 mm M804 practice projectile. The process covers the vertical airset molding, vertical pouring and induction melting. This report contains inspection, physical, chemical and metallurgical testing procedures incorporated during the production process. There is a summary on subcontractor performance on this contract. Also, contained in this report are tables and figures to aide in the understanding of the foundry practices and the tracking of each 155 mm M804 projectile cast. Dynamic tear properties are contained in the last section of this report.

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INTRODUCTION

Wagner Castings Company was awarded Phase II of this contract after the completion of Phase I evaluations. The second Phase effort was to qualify Ductile Iron as a material for the cast M804 Practice Projectile in a production environment. For the second phase Wagner Castings furnished labor, personnel, facilities, services, supplies, material, and equipment; except equipment furnished by the government, to cast and deliver 2000 acceptable projectiles. Vertical airset molding and vertical pouring techniques were used for the second phase of this contract. The vertical airset molding technique eliminated the use of chaplets to support the core prior to and during pouring and it proved to be very successful in the end results. Induction furnace melting, ladle treatment, cleaning and testing remained the same as in the first phase of this contract. A total of 3,215 mold cavities were made for this effort of which 3,168 were poured. A total of 2,268 projectiles were shipped to subcontractors for x-ray, machining, assembly, banding, painting, packaging, and inspection of all units in accordance with the appropriate government drawings and MIL-SPEC. An additional 268 projectiles were shipped to cover subcontractor's machining and testing scrap.

MOLDING PROCESS

Airset bonded sand was used to produce the molds in the second Phase of this contract because of its broad availability and economic considerations(*see Table 1 Borden Chemical Technical Data package)*. The use of airset molding eliminated the use of chaplets to hold the core in place during the pouring of the mold. The sand was produced in a "Dependable" continuous sand mixer (rated at 290 pounds per minute) in the contractor's Malleable facility with the following parameters:

1. Permeability	60 - 80 (unitless numbers)
2. Mold Hardness	85 - 100 (unitless numbers)
3. Sand Tensile Strength	150 - 250 PSI
4. Combustible LOI	1.0 - 2.0 %

The bonding of the sand for the airset utilizes a Phenolic Urethane whose mixture is controlled by metering at the mixing machine. This material has high tensile strength, which means it maintains a better surface finish, restricts growth during the solidification phase and enhances the ability to eliminate internal shrink. The airset sand is prepared as needed, to make molds and is introduced into the mold/flask (*see Figure 1*) and pattern (*see Figure 2*) automatically through an auger. Each mold was sequentially numbered prior to introducing the sand into the mold (*see Table 2*). The airset sand is manually compacted around the mold cavity surface using a hard leveling board. Once the flask is full of sand, the excess was struck off (leveled). The molding is done within 10 minutes, which is the workable time of the airset sand.

After 15 - 20 minutes full cure time was reached, the mold/flask was stripped from the pattern/locator pins, placed on a pallet for further processing. Periodically, the pattern was sprayed with a mold release agent to allow ease of removal of the mold from the pattern.

The mold (*see Figures 3 and 4*) was then taken to assembly area as needed, there they are assembled for pouring. At this point cores and exothermic risers were set into their print. After qualifying fixture was used to verify core location (side to side), fixture was removed and the mold halves was set together utilizing locator core/pin. The molds was clamped together in groups of three by the use of 1/2" steel plate and 1" off-set threaded rods. Each set of molds were torqued together to 90 psi in increments of 30 psi to hold each mold in place during pouring. At this point molds were placed into the pouring area vertically, awaiting arrival of iron for pouring.

CORE MAKING PROCESS

For this contract, the airset core making process (*see glossary*) was chosen because of strength, ease of operation and shelf life of the cores.

Core boxes (*see glossary*) were produced by a local vendor (Phipps Pattern, Decatur, Illinois) and were produced using aluminum frames or boxes with molded urethane liner. Core sand was mixed in a Beardsley-Piper muller in 50-pound batches. Chemicals (Part A and Part B) were weighed and added after the base sand (as received, washed lake sand, sub-angular, low clay content) had mulled for several minutes with one pound of iron oxide. After the catalyst (Catalyst 3500) was added, approximately ten minutes passed until the sand became unworkable and required the box (core) to be stripped or removed.

During this addition of the sand into the core box, a steel square tube (1/2" X 1/2", SAE 1010, 22 inches long) with vent holes along the shaft was rammed into the soft sand mixture. The purpose of this tube was to allow the gas to escape after iron was poured around the core. This tube extended beyond the core print (*see Figure 5*), into the mold face. This well was connected to the outer mold surface via a cut-in shaft to the cope surface. After the cure time was reached, the cores were stripped and hand-carried to a storage area for further processing. Periodically, a release agent was sprayed on the core box surface to allow ease of removal of the core.

Within 8 hours of use, the cores were dipped into a wash/coating (alcohol-base) to produce a smooth surface on the core and consequently produce a smooth surface on the casting interior. The wash also aids in preventing thermal cracking of the core, which causes core veins.

After dipping into the wash, the cores are placed into a hold area and flame dried (the core wash is hygroscopic and absorbs and retains moisture during high humidity). After leaving the drying area, the cores were taken to the mold assembly area as needed and set into the mold.

MELTING AND POURING

For the performance of this contract, all melt processes were directed from the contractor's Malleable Melt Center. The equipment used to melt the primary metal was a Brown - Boveri IT-6, 9 ton Coreless Induction Melt Furnace, rated at 2250 maximum kilowatts. Prior to any material being introduced into this furnace, all charge materials (metallic) were preheated in Brown - Boveri designed preheaters rated at 15 million BTU's/hour. Preheaters are used to remove any latent moisture and to reduce the BTU's (energy) needed to melt the charge material and bring the bath up to tap temperature. The recharge materials are:

2,250 pounds of purchased steel scrap
2,250 pounds of in-house returns (sprue or scrap)
100 pounds of graphite
8 pounds of silicon carbide

The additional 108 pounds make up for melting losses due to oxidation. the graphite was added to help renucleate the furnace bath, this graphite was composed of finely ground carbon electrodes. The silicon carbide (64% silicon, 28% carbon) addition was made to assist in deoxidizing the furnace bath. The furnace bath was heated until it reached the predetermined temperature of 2700° - 2760° F, at which time the furnace was ready to tap.

Various checks were made on the iron to verify the composition before the tap was made. Among these were; solidus/liquidus cooling curve (Thermal Analysis), chemical composition via Baird Spectrometer and temperature via immersion thermocouple, also carbon/sulfur analysis and Atomic Absorption verification/backup of Baird Spectrometer. Upon verification of the bath integrity, the iron was tapped into 1500 pound treatment ladles. Tap temperatures ranged from 2760° to 2,800° F. Treatment was accomplished by introducing the iron into the vessel with the following:

1. **29 pounds Magnesium Ferro-Silicon alloy:** MgFeSi consists of 6% Mg, 45% Si, 0.5% Ba and 1.2% Ca. This alloy results in the deoxidation and desulfurization of the iron being treated. Resulting magnesium recoveries on final iron ranged from .035% to .045%.

2. **5 pounds Ferro-Silicon (75% Si, 3/8" screen size):** 75% FeSi consisted of 72% - 78% Si, .90% - 1.25% Ca and .60% - 1.20% Al. This alloy, referred to as an inoculant, increases the nucleation sites for graphite nodule formation and eliminates the possibility for chill carbide formation.

3. **2-4 pounds Copper Shot:** Cu consisted of 99.7% copper shot. Proportion was dependent upon the level of copper in furnace at time of treatment. Addition was made after magnesium alloy has been placed into the treatment ladle. The purpose of this addition is to stabilize pearlite formation and consequently control hardness.

Post inoculation was made to the iron during transfer into each pouring ladle (500 pounds). This was in the form of 3/8" screen size material in the amount of 2 pounds per ladle.

Ladles were then brought to the pouring area via overhead rail system and pouring began after the temperature was verified using an immersion pyrometer. Pouring temperatures were held to 2580° - 2450° F. for Phase II of this contract.

During the pouring additional samples were taken to verify the chemistry and microstructure (*see Table 3*). While the iron was being poured into the mold, a lab technician was monitoring pouring times (20-25 seconds) and filling turbulence. Iron was poured with the mold in a vertical position until metal filled the pouring cup and the exothermic risers. After pouring, molds were taken to shakeout area to cool for approximately 2 1/2 to 3 hours; this was to assure consistent matrix microstructure and hardness.

SHAKEOUT AND FINISHING

After cooling in the shakeout area for approximately 2 1/2 to 3 hours all air set material is removed from around projectile gating, and exothermic riser and placed in separate containers.

The projectile is separated from the gating and exothermic risers by the use of a hammer. After separation the projectile (*see Figure 6*) is placed into a steel container and taken to finish area. The exothermic risers and gating were placed into steel containers and taken to Melt Department in-house return area (sprue). Melt Department will use exothermic risers and gating as returns in the make-up of recharge material on a control basis to be introduced into the melt furnace.

Steel containers of parts are taken to grinding station and there a counterbalance hook on an overhead hoist is used to allow easy handling of projectiles. The hook was inserted into cavity and moved to desired working position at grinding station. For the grinding, a portable disc grinder with a 9" diameter disc; rated at 5000 rpm was used. The exothermic riser connection, fill gates, parting line and cored opening were the only areas requiring any grinding. These areas were held to +.030 flush by the grinder. Upon finishing the grinding portion, the grinder off-loaded the projectile back into steel containers for transfer to cleaning area.

CLEANING

The projectiles furnished to the Army for Phase II of this contract were cleaned in a traditional steel shot cleaning machine after grinding operation. The machine was a 14 cubic foot, single wheel, Wheelabrator cleaning machine utilizing steel shot of a 330 to 440 screen size.

Parts were bulk loaded into the cleaning machine via metal dump box with approximately 10 projectiles making up a cleaned lot. The action of the wheelabrator blast is liken to a large vat tumbling the parts while a high speed wheel throws the steel shot at the mass of parts in the wheelabrator for the entire cleaning cycle. Cleaning time was approximately 15 minutes, this resulted in a extremely clean exterior and also a clean interior. The parts were bulk dumped from the wheelabrator onto a pan shaker and shaken into same metal containers from approximately 3 feet. After cleaning parts were taken to inspection and testing area.

TESTING AND INSPECTION

Upon receipt at the Quality Control Inspection station, the parts were placed on a workbench where they were visually inspected for (interior and exterior) surface defects. The Quality Control Inspector's criteria for visual inspection was: Exterior - no defects which were more than .060 inch deep, Interior - no visual defects allowed. The Inspector would then inspect the interior for any core veins, sand or core wash; if any were encounted, he would remove them with an abrading tool which was constructed for use with the M804. This tool was comprised of a shaft approximately 22 inches long and three chains, with a stainless ball on each. A second shaft with a round head grinding stone on the end was also used. The shaft was placed in a 1/2hp hand drill. The high speed turning caused the balls/grinding stone to strike the interior surface and knock any foreign material loose.

After a thorough cleaning of the interior, the Inspector used a Panametrics 22DLHP Ultrasonic Thickness gage to determine the concentricity of the core to exterior surface. The concentricity was important as it referenced the machine locating surface to the surface to be machined.

A log was maintained for this information and an example is contained in this report*(see Tables 4 and 5)*. Any projectile which exhibited an off-center condition and would cause the projectile to not clean-up was scrapped and confirmed on the tracking report*(see Tables 1 and 6)*.

Upon completion of inspection, the parts were taken to the brinell test machine (NewAge Model 8000 Automatic) where they were prepared and tested per *ASTM E-10,* both with digital readout on the machine and verified with a Bausch and Lomb 10x brinell scope. Hardness results are also included in the tracking report.

After hardness testing, all parts were returned to the Quality Control Inspection station where they were rustproofed in a water-based synthetic (Research Solvent and Chemical Company - Resco Oxy-Koate Syn-CC). The coating was then inspected.

After all testing was completed, a drilling of the center hole was performed. This center hole will be utilized to identify the centerline of the internal cavity with respect to the exterior surfaces for reference purposes. This hole will be located by placing each projectile in a vertical position over a centering fixture. This was done with the use of a sling device on a overhead hoist for the ease of handling. The core open, or fuze end is placed over a 18 inch arbor post having at it's top an expanding mandrel located concentric with base of the arbor post and will assure the alignment of the center cavity in a vertical position. With the part positioned, the center hole was drilled into the base end of the projectile.

Parts were then palletized and the forms required for transfer were prepared. The pallet was then moved to shipping for accumulation for loading.

PHYSICAL, CHEMICAL AND METALLURGICAL TESTING

For the performance of this contract, certain testing parameters were required. They are:

1. Hardness Testing per *ASTM E-10*
2. Mechanical Testing per *ASTM E-8*
3. Microstructure Evaluation per *ASTM E-247*
4. Radiographic Evaluation per *MIL-STD 453*

In addition, Wagner Castings performed routine testing in accordance with policies which assured conformance with requirements of this contract, they included:

1. Chemical analysis of:
   a. Incoming scrap material
   b. Incoming alloy material
   c. Base Furnace iron
   d. Final iron (after full alloying)
2. Information Radiography

Samples of all results from the required testing are included in this report (*see Tables 7 and 8*), and are complete for any parts delivered to the Government. The parameters for the testing of material for this contract was based upon typical foundry practices which were constructed as follows:

1. Hardness Testing - each piece
2. Mechanical Testing - sample from each pouring ladle
3. Microstructure Evaluation - sample from each pouring ladle
4. Radiographic Evaluation - each piece, 0 and 90 degrees plus additional shot for base.

The additional testing Wagner performed was based upon received lost or for batches produced (Furnaces or Treatment ladles).

With the exception of the required radiographic evaluation, all testing was performed at Wagner Castings by Wagner personnel. Required radiographic evaluation was performed by XRI Testing, Inc. personnel as stipulated in contract modification. Final evaluation and approval for shipment was given by Wagner Castings personnel prior to acceptance at source.

SUBCONTRACTOR PERFORMANCE

For the performance of this contract, Wagner Castings obtained the services of Ferrulmatic, Inc. for the machining, magnetic particle testing, hydrotesting, banding, surface preparation, marking and shipment to Crane Army Ammunition Activity, Crane, Indiana. For the Radiographic requirement of this contract Wagner Castings utilized XRI Testing, Inc. as the subcontractor; their responsibilities included, shots of the sidewalls and base made at 0 and 90 degress.

Experience at the machine subcontractor was positive since this configuration of projectile had been performed at this facility before. Ferrulmatic was the machine subcontractor for Phase I of this contract. The expertise of machining and banding, which is extremely important, was available with the personnel at Ferrulmatic. All phases of testing and verification for performance of this contract were over-seen by in-house DCAS personnel and this was accomplished without incident or rejection.

In all, 2,264 pieces were produced by the machine subcontractor to cover any scrap, testing, or establishment of standards. The result of this exercise was positive, since all parts were not needed for the final delivery. The balance of the parts were returned to Wagner Castings for analysis, scrap, or de-militarization.

The radiographic subcontractor performed well also: parts were delivered and return was acceptable. Radiography took place after Wagner had approved the mechanical properties, metallurgy and visual condition of each projectile before shipping to the subcontractor. Radiography was performed by XRI Testing of Lima, Ohio using a 24 million volt Betatron Unit. The projectiles were radiographed in the 0 and 90 degree positions with additional film used to cover the base end thickness. Mil Standard-453 penetrameters were place on the base, bourrelet and ogive. Film densities were checked using an X-rite Model 301 Densitometer. The densitometer's readings were verified as being accurate, using a film strip calibrated and traceable to N.B.S.

The results of the radiographic evaluation of delivered parts were positive, with no parts having serious or unacceptable discontinuities. Required radiographic evaluation was performed by XRI Testing personnel as stipulated in contract modification. Final evaluation was made by Wagner Castings personnel and approval for shipment was given by Wagner personnel prior to acceptance by DCAS at source. A total of 2268 pieces were radiographed, 2264 pieces were accepted and shipped to machine subcontractor. In all 4 rejected pieces was returned to Wagner's and analyzed and scrapped.

DYNAMIC TEAR PROPERTIES OF 155MM M804 PROJECTILES

Contract DAAA21-87-C-0252, Modification P00009, requiring the testing of thirty (30) bars using the Dynamic Tear Technique, per *ASTM E604-83* Wagner Casting submits the following results. Forty bars were actually tested.

Part of the 155mm projectile contract was to measure the dynamic tear energies at -60°F of the material, pearlitic ductile iron, used in producing the projectiles.

Dynamic tear (D.T.): Is the measure of the toughness of the material to resist rapid progressive cracking. Dynamic tear can be used for correlation with established service performance of particular components. It is also used for evaluation of metallurgical process changes, materials, heat treatment, fabrications, and establishing nil ductility temperature.

Test Proccdure: Forty D.T. bars were poured along with 155mm projectile over a period of 16 heats. A heat consisted of one ladle of ductile iron which produced about nine projectiles. The bars were poured in vertical molds (*see Figure 7*).

The bar molds were made of the same material as the projectile molds. The bars were cleaned and X-rayed to insure internal integrity. The bars were machined and tested in accordance with *ASTM E604-83*, re-approved in 1988, (*see Figure 8*).

All of the bars were broken at -60°F. using a 10 foot drop tower and 220 pound tup. The drop tower was manufactured by MTS SYSTEMS CORPORATION. The forty bars are identified by heat number and Julian cast date (*See Table 10*).

Discussions of Results: The results of the tests are listed in Table 11. The initiation, propagation and total energies are given in the Table. To evaluate the variation of the data, a capability and process control analysis was determined, Table 12. The results of this analysis shows that D.T. data is very consistent with a Cpk value of 1.33. One energy value, Number 28, had a high value of 8.74 ft.lbs. Microstructure (*see Figure 9*) and chemistry analysis did not result in any reason for this deviation. However, examination of the broken bar shows that it was sitting diagonally to the anvils. Apparently, when the bar was placed on the anvils and fixture, it moved when the fixture was released.

On Table 13, page #33 the comparison of hardness versus Dynamic Tear Energy is given. There is a trend as the pearlite increases (hardness increases) the Dynamic Tear Energy will decrease. This is a result of the decrease in plasticity with corresponding tendency torward low energy cleavage fracture.

Additional Testing: Dynamic tear energy versus temperature curve was also completed. The temperature range for the curve was 150° to +150°F. The curve is on

Figure 10, page #44. The data is on Table 14, page #34. The upper shelf energy was not realized in this test. More than likely the maximum upper shelf energy is attained at 250° -300°F.

CONCLUSIONS

A total of 3,215 mold cavities were produced for this effort of which 3,168 were assembled and poured. Several problems were encounted during the course of production (see Table 9). Most notable of the in house problems were:

1. Minimum wall violation
2. Mechanical properties
3. Nodularity
4. Dirt inclusions

Minimum Wall Violation: Wagner Castings used a tight tolerance allowance in this contract to eliminate projectiles shipped to machinist that would not pass wall thickness specifications after machining. A qualifying fixture used during core setting procedure eliminated the majority of the minimum wall violation during production.

Mechanical Properties: During the course of production Wagner Casting discovered that some projectiles did not meet mechanical properties. Technical Department researched this problem from the base iron analysis, inoculated iron analysis, pouring ladle additions, pouring technique and the time between pouring and shakeout. After a careful study was conducted, the airset mold proved to be such a great thermally efficient mold, the cast projectile self- annealled (see glossary) in the mold prior to shakeout. A shakeout procedure was established immediately, all M804 projectiles were to be shook out of the mold within 2 1/2 to 3 hours maximum.

Nodularity: Less than 90% nodularity rating is used and accepted within the foundry industry; however Wagner's criteria is 90% or better as acceptance nodularity rating. Wagner's quality criteria in the commercial market is a nodularity rating of 90% or better and we would not ship the United States Army any projectiles less than 90%. We do feel the scrapped projectiles (due to nodularity rating) would have passed many foundries' acceptance criteria.

Dirt Inclusions: Commonly known as sand. Sand is the most widely used product to make molds and cores in the foundry industry today. At times, sand can lead to a signature defect that causes a casting to be scrapped. Again, our quality criteria was not to ship projectiles to the machine subcontractor we suspected would not clean-up during the machining operation.

In summation, all production on the 155mm M804 projectiles were performed on a one shift basis. With molding, core making, assembly, melting, pouring, cleaning and inspection done on our first shift. The shakeout and finishing operation was performed on the following shift. Wagner Castings has the facilities, capabilities, and the personnel to provide the United States Army a cast Ductile Iron 155mm M804 Projectile that meets or exceeds current demands.

TABLES

BORDEN®

THE ALpHASET® SYSTEM

AN ESTER CURED PHENOLIC NO-BAKE BINDER

The ALpHASET SYSTEM is a no-bake foundry binder system utilizing new, unique technology developed and patented by Borden. Providing improvements to the foundry environment, this two-part, water soluble resin system allows the production of improved quality castings.

Background

In the mid 70's Borden undertook a research program to develop an organic foundry binder system that offered: 1) Improvements to the foundry environment (internally/externally), 2) Superior casting performance like the 'silicate' binders, and 3) the advantages of existing 'organic binders'. The resulting product was the ALpHASET SYSTEM which is an alkaline phenolic resole cured with an organic ester. Initial introduction was made in England in the early 80's. and the ALpHASET SYSTEM is now a significant commercial binder throughout Europe and the United States.

The ALpHASET® Advantage

Sand Handling Characteristics

Designed for the foundryman, no other no-bake system offers all the advantages of the ALpHASET SYSTEM in the production of molds and cores.

Low Odor at Mix Station	Use any Sand
Low Chemical Toxicity	Excellent Pattern Release
Water Clean-up	Complete Through-set

The system advantages result in an improved environment, better employee acceptance/working conditions, less maintenance and increased production.

The next two tables compare the ALpHASET SYSTEM to other commonly used no-bake systems for the SAND handling and casting results.

ACME RESIN
Subsidiary of Borden, Inc.
10330 West Roosevelt Road
Westchester, Illinois 60153
312/343-1900 TWX 910/997-0751

Borden Chemical
Division of Borden, Inc.
INDUSTRIAL RESINS DIVISION
180 East Broad Street, Columbus, Ohio 43215
614/225-7426

FOR ADDITIONAL INFORMATION CONTACT YOUR LOCAL REPRESENTATIVE FROM ACME RESIN OR BORDEN INDUSTRIAL RESINS DIVISION.

TABLE I

SAND HANDLING COMPARISON OF ALpHASET® TO OTHER NO-BAKE SYSTEMS

	ALpHASET®	FURAN	PHENOLIC	PHENOLIC URETHANE	ALKYD ISOCYANATE	SILICATE ESTER
Odor At Mixing (Hot Sand)	V. Low	High	High	High	Moderate	V. Low
Pattern Release	Excellent	Poor	Poor	Poor	Excellent	Good
Water Cleanup	Yes	Partly	Partly	No	No	Yes
Work time to Strip time Ratio	30	25	25	50+	25	25
Effect of Hot or Cold Sand	Moderate	High	High	Moderate	Moderate	Moderate
Use Any Sand	Yes	No	No	Yes	Yes	No
Core/Mold Storage	Long	Long	Long	Medium	Medium	Short
Fast Set Times	Yes	Yes	No	Yes	No	No
Slow Set Times	Yes	Yes	Yes	No	Yes	Yes

TABLE II

CASTING COMPARISON OF ALpHASET® TO OTHER NO-BAKE SYSTEMS

	ALpHASET®	FURAN ACID	PHENOLIC ACID	PHENOLIC URETHANE	ALKYD ISOCYANATE	SILICATE ESTER
Nitrogen	No/Yes	Yes/No	Yes/No	Yes	Yes	No
Scab Tendencies	Low	Low	Low	Moderate	Moderate	Low
Sulfur	No	Yes/No	Yes	No	No	No
Veining Tendencies	Low	High	High	Moderate	Low	Low
Reclaimability	High	High	High	High	High	Low
Gas Defect Potential	Low	Moderate	Moderate	High	High	Low
Shakeout	Good	Moderate	Moderate	Moderate	Moderate	Poor
Lustrous Carbon	Low	Moderate	Moderate	High	High	Low
Pour Off Smoke	Low	Moderate	Moderate	High	High	Low
Hot Tear Potential	Low	High	High	Moderate	Moderate	Moderate

Casting Characteristics

Reduced expansion defects, such as veins and scabs, is a primary benefit of the ALpHASET SYSTEM: the chemistry of the system allows for the binder to absorb the initial sand expansion at pouring before final cure. Containing no or low 'nitrogen' and no 'sulfur', related gas defects are minimized and iron oxide addition is usually not necessary.

Steel Castings

The benefits of the ALpHASET SYSTEM are most noticeable in steel castings resulting in a significant improvement in casting quality and reduced cleaning-room costs. Expansion defects, inherent to steel metallurgy, are significantly reduced due to the systems unique thermosetting characteristics.

Binder related gas defects, common to steel castings, are markedly reduced or eliminated; the system contains no or low nitrogen, no phosphorous and no sulfur, all of which may impart gas defects. Most often, iron oxide addition can be eliminated.

On stainless and alloyed steels, there is reduced surface carbon pickup reducing problems in meeting 'surface carbon' specifications.

Aluminum Castings

The ALpHASET SYSTEM provides some specific benefits to aluminum and magnesium castings: improved shakeout and staining reduction/elimination. Shakeout times on cores/molds have been reduced by up to 50-90%; the resulting savings have been instrumental in the system's acceptance for aluminum castings.

THE ALpHASET® SYSTEM

The ALpHASET SYSTEM is a two component liquid binder system. Part I, the ALpHASET resin, is a water-soluble, alkaline, phenol-formaldehyde polymer. Part II, the ALpHACURE® hardener/co-reactant, is a blend of organic esters. Various ALpHACURE co-reactants are available to provide the desired "work/strip" times; the ALpHACURE co-reactant must be used in the specified ratio to resin to develop an optimum sand bond.

RESINS

Resins

The following resins are available:

Typical Properties

	ALpHASET (9000/9010)	ALpHASET (9005/9015)
Color	Red-Dark Red	Red-Dark Red
Viscosity, cps	150	150
Spec. Gravity	1.29	1.22
Water Solubility	Infinite	Infinite
Solids, %	55	50
pH	13	12
Free Formaldehyde, %	0.5	0.5
Flash Point, SETA	220°F min.	120°F min.
Free Phenol, %	2	2
ALpHACURE Useage	25% B.O.R.	17% B.O.R.
Nitrogen	0%/1%	0%/1%
Storage Stability:		
90°F	3 months	1 month
75°F	4 months	2 months
41°F	†6 months	†3 months

Handling: The ALpHASET resins are high alkaline, phenolic resoles and normal care for chemicals should be used when handling them, including protective gear such as gloves and face shields. Consult the "Material Safety Data Sheet" ("MSDS") for specific information.

Co-Reactants

The following co-reactants (hardeners) are available to provide varying "work/strip" times:

ALpHACURE	Strip Time*(min)	ALpHACURE	Strip Time*(mi
902	2	915	15
903	4	920	20
9C5	6	930	30
907	8	960	60
910	10		

* Strip Times were determined at room temperature (80°F) using ALpHASET 9000 on Wedron sand. Depending on type sand, ambient conditions and type resin, the strip time will vary and should be determined under your specific plant conditions. In most cases, the ALpHASET SYSTEM will produce a 'Work Time' up to 35% of the 'Strip Time'.

Typical properties on the ALpHACURE co-reactant organic esters are:

Color	Clear-Straw
Spec. Gravity	1.1-1.2
Flash Pt., SETA	198°F
Storage Stability	2 years

Handling: As with all chemicals, protective clothing, gloves and face masks should be used. Consult the "MSDS" for specific information.

Mix Levels

The ALpHASET resin is used at conventional levels on silica sand: 1-2% based on sand weight. On Olivine or very fine, angular sands, higher levels may be required.

The ALpHACURE ester co-reactant useage level varies with the specific ALpHASET resin used, as follows:

	ALpHASET 9000/9010	ALpHASET 9005/9015
ALpHACURE	25% B.O.R.	17% B.O.R.

Since the ALpHACURE hardener is a co-reactant, its ratio to resin should not be changed as it can significantly alter the physical and casting quality of the system.

Mixing

As with any foundry binder system, the quality of mixing of the two components is critical to developing the optimum system performance. The ALpHASET resin and ALpHACURE hardener must have intimate contact and mixing while being coated on the sand. In a few cases we have found that some mixers and/or the conditions of some mixers are not adequate due to the low levels of ALpHACURE hardener used. To assure good metering and mixing, the ALpHASET resin should approximate room temperature at the time of use.

On continuous mixers, either the resin or hardener can be added first; it is, of course, recommended that they be added as early as possible to the sand stream. On batch (muller) mixing, add the hardener first; if premixing the resin/hardener system before addition, it should be mixed and added as rapidly as possible to avoid pre-cure. Mixing/mulling time should be consistent with the system "worklife" or poor composite properties will result. Tensile strengths obtained with batch mixers are generally much lower than those obtained with high speed continuous mixers.

Cure and Characteristics

The ALpHASET SYSTEM is a 'through-cure' system, i.e., the curing mechanism proceeds at the same rate throughout the mold/core. When the strike-off surface is hard, the pattern face is also. This makes "Strip-Time" determination easy and consistent.

The reaction speed is determined by the ALpHACURE co-reactant used, not by the quantity employed; always use the quantity of ALpHACURE recommended for the specific ALpHASET resin.

While the ALpHASET SYSTEM is less affected by sand temperatures than many other organic binder systems, sand temperatures do affect the reaction rate and the 'Work/Strip' time. Using the ALpHACURE 905 reactant, strip times will vary with sand temperature: 40°F - 12 min., 75°F - 6 min., 125°F - 2 min. We, or course, recommend the use of "constant-temperature" sand; needless to say, this is not always practical. Wide variations in sand temperatures may require selective use of different ALpHACURE co-reactants. The use of sand heaters and coolers to control sand temperature is recommended.

Refractory Coatings

The ALpHASET SYSTEM bond is somewhat soluble in the water/solvents used in wash coatings. Proper drying techniques are required for good system performance. Surface hardening of the core surface before applying the coating is a desirable practice.

Alcohol washes should be ignited immediately after coating; a light torch drying has also been found helpful. On water-based washes, external heat (torch or oven) is necessary to vaporize the water; dry until no further steam comes off the sand but avoid excessive heat and/or oven cure. Modest heating prior to washing has also been found to be helpful.

Pattern Release

The ALpHASET SYSTEM releases extremely well, much like an alkyd and far superior to most other no-bake systems. Pattern release agents should be minimized.

Sand Reclamation

The preferred method of reclamation is mechanical dry attrition. Thermal reclamation is not recommended.

The control of ALpHASET bonded reclaim sand differs from conventional techniques due to the nature of the chemistry. The specific differences in techniques are caused by two factors: 1) the residual inorganics, and 2) the non-reactive diluent.

As with all reclamation systems, the loss on ignition is an important test to run. The ALpHASET SYSTEM reclaims and bonds very well when the L.O.I. is under 1%. This will insure that the residual inorganics will not affect the rebonding strength and melt point of the sand. It is important to note that the L.O.I. of an ALpHASET SYSTEM will be significantly lower than that of conventional no-bake systems. As the L.O.I. approaches 1.5%, rebond strength will deteriorate. The key to good reclamation is fines extraction from the sand. An L.O.I. on the 200 mesh material may be 10 times the L.O.I. on 50 mesh sand.

The ALpHASET SYSTEM can utilize up to 80-90% reclaimed sand which is generally very acceptable in the industry. It is important that the new sand addition or makeup sand is blended into the reclaimed sand versus coming in surges. The ALpHASET SYSTEM reacts differently between new sand and reclaimed sand with regard to speed of cure. By blending, the foundry can obtain uniformity in the rate of cure and tensile strength.

An alternate method is facing the core or mold with new sand and backing it up with 100% reclaim sand. This has the advantage of having the highest strength sand always against the metal.

Aluminum foundries will see less sand burn out due to less thermal degradation of the binder. The optimum levels of reclaimed sand for aluminum castings may be from 50 to 80% depending on the quality of the reclaimer in use. As with any no-bake system, it is important to monitor the quality of reclamation for a period of time.

Trouble Shooting

In most cases, if the ALpHASET SYSTEM stops performing as expected, the problem lies in the mixing of the chemicals. The mixing problem can arise from several areas:

1) Pumps not delivering required quantity of chemicals.

2) Mixer not picking up or utilizing the amount of hardener required.

3) Inadequate mixing due to lack of energy or intensity.

The early indicator of poor mixing is a fall off of strengths or a different color pattern of the cured new sand. If reddish spots or areas appear, the binder is not getting enough hardener. If the amount of hardener gets out of the specific range in either direction, strengths deteriorate.

<u>Core Softness</u> after washing is an indication that the wash was not dried sufficiently.

<u>Core degradation</u> after a few days is an indicator of a poor mix or where the chemicals were not intimately mixed.

<u>Burn-in</u> on castings is caused by poor sand density, poor mixing, out of balance mix or improper drying of the wash.

<u>Long set times</u> are an indication that the sand has been moved after the useable work time for the system. A slower ALpHACURE may correct the problem.

The AlpHASET Advantage

... is Quality Castings

We would like the opportunity to demonstrate the range of benefits within your own operation. For more information and in-plant evaluation, please contact us now.

TABLE 2

155MM M804 PROJECTILE

DAAA21-87-C-0252

TRACKING REPORT

MOLD SERIAL #	MOLD DATE	JULIAN POUR DATE	BHN READING	STRENGTH TENSILE	STRENGTH YIELD	PERCENT ELONG A	DISPOSITION	DATE SHIPPED	X-RAY APPROVED	SHIPPED CRANE
825	06-Apr-89	101	3.95	111,659	62,627	11.0%		25-May-89	OK-4	Lot #3
826	06-Apr-89	101	3.80	111,659	62,627	11.0%		05-May-89	OK-3	Lot #2
827	06-Apr-89	101	3.80	111,659	62,627	11.0%		25-May-89	OK-4	Lot #3
828	06-Apr-89	101	3.95	111,659	62,627	11.0%		21-Apr-89	OK-2	Lot #1
829	06-Apr-89	101	3.95	111,872	74,581	10.0%		25-May-89	OK-4	Lot #3
830	06-Apr-89	101	4.00	111,872	74,581	10.0%		05-May-89	OK-3	Lot #2
831	06-Apr-89	101	3.80	111,872	74,581	10.0%		05-May-89	OK-3	Lot #2
832	07-Apr-89	101	3.90	111,872	74,581	10.0%		05-May-89	OK-3	Lot #2
833	07-Apr-89	101	3.90	111,872	74,581	10.0%		05-May-89	OK-3	Lot #2
834	07-Apr-89	102	4.05	113,798	63,696	8.5%		05-May-89	OK-3	Lot #2
835	07-Apr-89	102	4.20	113,798	63,696	8.5%		05-May-89	OK-3	Lot #2
836	07-Apr-89	102	4.05	113,798	63,696	8.5%		05-May-89	OK-3	Lot #2
837	07-Apr-89	101	4.00	111,872	74,581	10.0%		25-May-89	OK-4	Lot #3
838	07-Apr-89	101	3.90	111,872	74,581	10.0%		25-May-89	OK-4	Lot #3
839	07-Apr-89	102	*	*	*	*	SCRAP-BUILD UP IN ID			
840	07-Apr-89	**	*	*	*	*	SCRAP-MOLD			
841	07-Apr-89	102	4.05	113,798	63,696	8.5%		05-May-89	OK-3	Lot #2
842	07-Apr-89	102	4.05	113,798	63,696	8.5%		05-May-89	OK-3	Lot #2
843	07-Apr-89	102	4.10	113,798	63,696	8.5%		05-May-89	OK-3	Lot #2
844	07-Apr-89	101	4.05	115,325	62,627	7.0%		05-May-89	OK-3	Lot #2
845	07-Apr-89	101	3.90	115,325	62,627	7.0%		25-May-89	OK-4	Lot #3
846	07-Apr-89	101	3.95	115,325	62,627	7.0%		25-May-89	OK-4	Lot #3
847	07-Apr-89	101	4.10	115,325	62,627	7.0%		05-May-89	OK-3	Lot #2
848	07-Apr-89	101	3.80	111,872	74,581	10.0%		05-May-89	OK-3	Lot #2
849	07-Apr-89	101	3.90	115,325	62,627	7.0%		05-May-89	OK-3	Lot #2
850	07-Apr-89	101	4.10	111,872	74,581	10.0%		05-May-89	OK-3	Lot #2
851	07-Apr-89	101	4.00	115,325	62,627	7.0%		05-May-89	OK-3	Lot #2
852	07-Apr-89	101	3.80	115,325	62,627	7.0%		05-May-89	OK-3	Lot #2
853	07-Apr-89	101	3.95	115,325	62,627	7.0%		25-May-89	OK-4	Lot #3
854	07-Apr-89	101	3.85	111,659	62,627	11.0%		21-Apr-89	OK-2	Lot #2
855	07-Apr-89	101	3.85	113,340	62,627	10.0%		25-May-89	OK-4	Lot #3
856	07-Apr-89	101	4.00	111,659	62,627	11.0%		05-May-89	OK-3	Lot #2
857	07-Apr-89	101	3.80	113,340	62,627	10.0%		25-May-89	OK-4	Lot #3
858	07-Apr-89	101	3.90	113,340	62,627	10.0%		05-May-89	OK-3	Lot #2
859	07-Apr-89	103	4.10	114,562	62,932	10.0%		25-May-89	OK-4	Lot #3
860	07-Apr-89	103	4.05	114,562	62,932	10.0%		05-May-89	OK-3	Lot #2
861	07-Apr-89	103	4.00	114,562	62,932	10.0%		25-May-89	OK-4	Lot #3
862	07-Apr-89	103	4.10	114,562	62,932	10.0%		05-May-89	OK-3	Lot #2
863	07-Apr-89	103	3.95	114,562	62,932	10.0%		25-May-89	OK-4	Lot #3
864	10-Apr-89	102	3.80	109,215	63,085	11.0%		25-May-89	OK-4	Lot #3
865	10-Apr-89	102	4.10	109,215	63,085	11.0%		25-May-89	OK-4	Lot #3
866	10-Apr-89	102	4.15	111,507	61,710	11.0%		25-May-89	OK-4	Lot #3
867	10-Apr-89	102	4.15	111,507	61,710	11.0%		25-May-89	OK-4	Lot #3
868	10-Apr-89	102	4.05	111,507	61,710	11.0%		05-May-89	OK-3	Lot #2

TABLE 3

WAGNER CASTINGS COMPANY
PRODUCT INFORMATION
155M804 PRACTICE PROJECTILE

Daily Metallurgical Data . Date: 7-18-89

Green Sand/Facing Sand

Time of Analysis	Perm.	Temp.	Tensile	Spec. Wt.	Core Gas	Compact.	Comb.
7-17-89	62	97°	230 Psi	176.7	1.3%	36	1.7%
7-18-89	138	101°	154 Psi	154.1	1.8%	41	2.2% 1.2%

Core Binder: Nova Set Molds ... Nova Cure Cores
Type of Wash: Z-50 Alcohol Base Cores Only

Base Metal Chemistry

Time of Analysis	C	Si	Cu	Mn	Cr	B	S	Ni	Mo	Ti	Sn	Al	Pb	Zn	P

Final Iron

Tap Time	5^{47} AM	6^{33} AM	7^{57} AM	9^{15} AM	11^{55} AM	12^{58} PM	1^{48} PM	2^{55} PM			
Heat Number	6008	6009	6010	6011	6012	6013	6014	6015			
Carbon Equival.	2135	2135	2135	2135	2134	2134	2134	2134			
# of Castings	9	9	9	6	9	9	9	9			
T.L. Mg FeSi	32	31	31	31	31	31	31	31			
T.L. FeSi	—	—	—	—	—	—	—	—			
T.L. Cu	3# 4oz	3# 4oz	3# 4oz	—	2# 4oz	2# 4oz	2# 4oz	2# 4oz			
P.L. FeSi	3.5	3.5	3.5	3.5	2.5	2.5	2.5	2.5			
P.L. Cu	1.5	1.5	1.5	2# 10oz	1.5	1.5	1.5	1.5			
Temp./Tap	2720	2720	2740	2720	2720	2720	2720	2720			
Temp./Pouring											
C											
Si											
Cu											
Mg											
Mn											
Cr											
Nodularity	100%	100%	100%	95%	100%	100%	100%	100%			
% Ferrite/BHN											
Tensile Stren.											
Yield Stren.											
Elong. %											

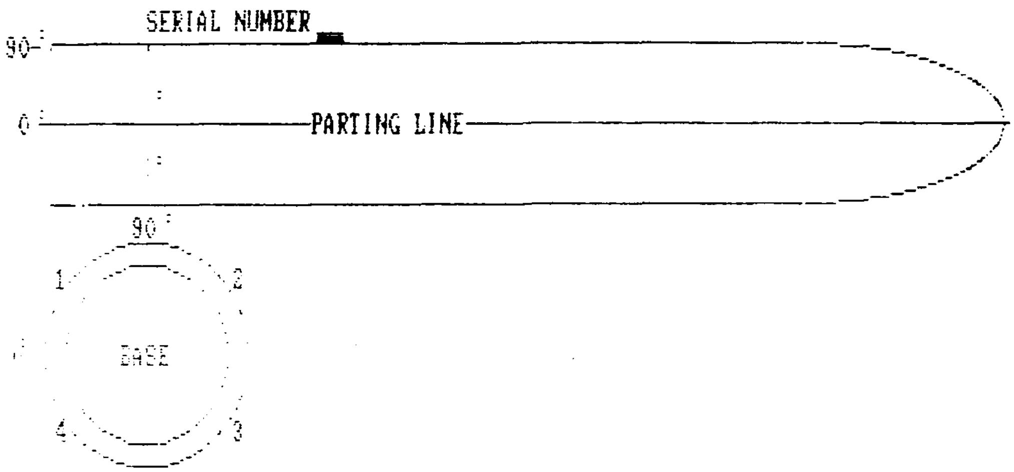
Comments:

TABLE 4

WAGNER CASTINGS COMPANY

155 M804 PRACTICE ROUND
ULTRASONIC THICKNESS VERIFICATION

INSPECTION DATE: 08/18/89 INSPECTOR: WEH



CASTING#	BASE 1	2	3	4	T.I.R
3145	1.548	1.508	1.463	1.493	0.085
3148	1.703	1.619	1.363*	1.451	0.340
3156	1.573	1.497	1.476	1.545	0.097
3157	1.532	1.464	1.509	1.563	0.099
3158	1.715	1.516	1.366*	1.507	0.349
3159	1.625	1.499	1.446	1.557	0.179
3160	1.567	1.544	1.478	1.486	0.029
3161	1.589	1.494	1.425	1.524	0.164
3176	1.681	1.797	1.34[illegible]*	1.258*	0.539
3177	1.635	1.559	1.430	1.502	0.205
3178	1.577	1.466	[illegible].435	1.641	0.206
3201	1.595	1.419	1.462	1.534	0.215
3202	1.551	1.553	1.472	1.483	0.081
3213	1.699	1.551	1.351*	1.570	0.348
3214	1.619	1.490	1.419	1.508	0.200

BASE MINIMUM THICKNESS = 1.375

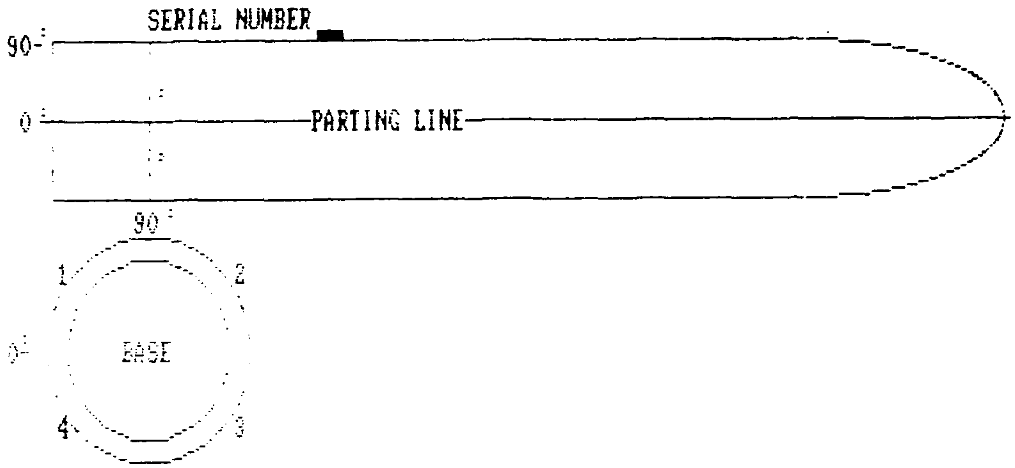
---------------------- END REPORT ----------------------------------

TABLE 5

DIRECTIONAL SUMMARY

155 M804 PRACTICE ROUND

INSPECTION DATE: 08/18/89 INSPECTOR: WEH



CASTINGS WITH MINIMUM THICKNESS AT SITE # 1 = 0
CASTINGS WITH MINIMUM THICKNESS AT SITE # 2 = 2
CASTINGS WITH MINIMUM THICKNESS AT SITE # 3 = 12
CASTINGS WITH MINIMUM THICKNESS AT SITE # 4 = 1

TOTAL NUMBER OF CASTINGS TESTED = 15

TABLE 6

PROCESS/INSPECTION CHECKLIST
155 MM PROJECTILE

JULIAN CAST DATE: ______

INSPECTOR: ______

CAVITY NUMBER	GRIND	BHN	EXTERNAL INSPECT	INTERNAL INSPECT	ULTRA-SONIC	RUST-PROOF	SCRAP	HOLD	SHIP
1825	OK	380	OK	OK	OK	OK	—	—	SHIP
1826	OK	370	OK	OK	OK	OK	—	—	SHIP
1827	OK	400	OK	OK	OK	OK	—	—	SHIP
1828	OK	375	OK	OK	OK	OK	—	—	SHIP
1829	OK	375	OK	OK	OK	OK	—	—	SHIP
1830			BOIL		OK		SCRAP		
1831	OK	390	OK	OK	OK	OK	—	—	SHIP
1832	OK	380	OK	OK	OK	OK	—	—	SHIP
1833	OK	390	OK	OK	OK	OK	—	—	SHIP
1834	OK	385	OK	OK	OK	OK	—	—	SHIP
1835	OK	370	OK	OK	OK	OK	—	—	SHIP
1836	OK	395	OK	OK	OK	OK	—	—	SHIP
1837	OK	380	OK	OK	OK	OK	—	—	SHIP
1838	OK	370	OK	OK	OK	OK	—	—	SHIP
1839					Minual		SCRAP		
1840				CORE BROKE			SCRAP		
1841	OK	380	OK	OK	OK	OK	—	—	SHIP
1842	OK	380	OK	OK	OK	OK	—	—	SHIP
1843	OK	390	OK	OK	OK	OK	—	—	SHIP
1844			Hole in Gate				SCRAP		
1845	OK	380	OK	OK	OK	OK	—	—	SHIP
1846			Bust out				SCRAP		
1847	OK	395	OK	OK	OK	OK	—	—	SHIP
1848	OK	385	OK	OK	OK	OK	—	—	SHIP

TABLE 7

TYPE OF CASTING: 155mm DATE POURED: 7-18-89

HEAT #: 6008
METALLURGY: Good

POUR ORDER	CAST #	COMMENTS
1	2900	
2	2899	
3	2898	
4	2897	
5	2896	
6	2895	
7	2894	
8	2893	
9	2892	
10		
11		
12		

HEAT #: 6009
METALLURGY: Good

POUR ORDER	CAST #	COMMENTS
1	2891	
2	2890	
3	2889	
4	2888	
5	2887	
6	2886	
7	2885	
8	2884	
9	2883	
10		
11		
12		

HEAT #: 6010
METALLURGY: Good

POUR ORDER	CAST #	COMMENTS
1	2876	
2	2875	
3	2874	
4	2873	
5	2872	
6	2871	
7	2882	
8	2881	
9	2880	
10		
11		
12		

HEAT #: 6011
METALLURGY: Good

POUR ORDER	CAST #	COMMENTS
1	2879	
2	2878	
3	2877	
4	2870	
5	2869	
6	2868	
7		
8		
9		
10		
11		
12		

T. D. FORM # 502-RO-87

TABLE 8

WAGNER CASTINGS COMPANY
PRODUCT INFORMATION
155M804 PRACTICE PROJECTILE

Metallurgical Data(By Tap)

Date: 7-18-89 JULIAN DATE 199
Heat Number: 6008
Tap Time: 547 A.M. P.M.
Number of Molds Poured: 9 MICRO FILE 148
Tap Temperature: 2720 °F
Carbon Equivalent: 2135

Base Metal Chemistry(Hard Copy):

Ram Screen Preserve Error # 2Ram Screen Preserve Error # 2Ram Screen Preserve Error # 2DUCT 2 4:26

FK	C	SI	MN	CR	AL	B	S	P	CU	NI	TI	SN	MO	CE CA	LIQ C	D.LIQ	AC C
94.25	3.86	1.41	.27	.027	.0005	.0009	.010	.012	.138	.017	.0006	.0013	.006	4.26	0	.0	00

Pouring Temperature

Mold			
Mold 2900	7-17	2522	°F
Mold 2899			°F
Mold 2898			°F
Mold 2894			°F
Mold 2893		2497	°F
Mold 2892			°F
Mold 2897			°F
Mold 2896			°F
Mold 2895		2451	°F

FADE OUT 8MM 40SEC
SHAKEOUT TIME 2½ HRS

Final Chemistry(Hard Copy):

HT #6008 7-18-89 155mm

Specification : LINE 2 FINAL DUCTILE 1 FINAL 7/19/89 14:04

CV	C	SI	MN	CR	AL	B	S	P	CU	NI	TI	SN	MO	MG
2595	3.74	2.68	.23	.029	.0234	.0011	.010	.012	.610	.018	.0030	.0043	.004	.041

TABLE 9
PARETO ANALYSIS

SCRAP DESCRIPTION	TOTAL SCRAP	MOLDS MADE (3215) PERCENT VS MOLDS	MOLDS MADE (3215) PERCENT BY DEFECTS	MOLDS POURED (3168) PERCENT VS MOLDS	MOLDS POURED (3168) PERCENT BY DEFECTS
MACHINE SHOP (SUB-CONTRACTOR)	208	6.470%	17.479%	6.566%	18.198%
MINIMUM WALL VIOLATION	194	6.034%	16.303%	6.124%	16.973%
FAILED PHYSICALS	138	4.292%	11.597%	4.356%	12.073%
NODULARITY	89	2.768%	7.479%	2.809%	7.787%
DIRT	89	2.768%	7.479%	2.809%	7.787%
BRINELL SOFT	84	2.613%	7.059%	2.652%	7.349%
CORE BROKE	69	2.146%	5.798%	2.178%	6.037%
BOILED	56	1.742%	4.706%	1.768%	4.899%
MOLD (NOT POURED)	47	1.462%	3.950%	1.484%	xxxxx
CUT FOR TENSILE	29	0.902%	2.437%	0.915%	2.537%
BANDING TEST (SUB-CONTRACTOR)	29	0.902%	2.437%	0.915%	2.537%
EXOTHERMIC RISERS	26	0.809%	2.185%	0.821%	2.275%
BUST OUT	17	0.529%	1.429%	0.537%	1.487%
BRINELL HARD	15	0.467%	1.261%	0.473%	1.312%
HOLE IN GATE	14	0.435%	1.176%	0.442%	1.225%
BUILD UP IN CORE CAVITY	11	0.342%	0.924%	0.347%	0.962%
POUR SHORT	10	0.311%	0.840%	0.316%	0.875%
WABEL TOOL EXPERIMENT	9	0.280%	0.756%	0.284%	0.787%
MOLD BROKE	7	0.218%	0.588%	0.221%	0.612%
OTHERS	7	0.218%	0.588%	0.221%	0.612%
SURFACE INCLUSIONS	6	0.187%	0.504%	0.189%	0.525%
X-RAY VERIFICATION	5	0.156%	0.420%	0.158%	0.437%
VISUAL DEFECTS	5	0.156%	0.420%	0.158%	0.437%
SLAG	4	0.124%	0.336%	0.126%	0.350%
SCRAP AFTER X-RAY (SUB-CONTRACTOR)	4	0.124%	0.336%	0.126%	0.350%
GRIND IN DEFECTS	4	0.124%	0.336%	0.126%	0.350%
PATTERN CHECK	4	0.124%	0.336%	0.126%	0.350%
CORE VEINS	3	0.093%	0.252%	0.095%	0.262%
DUPLICATION OF SERIAL NO	3	0.093%	0.252%	0.095%	0.262%
COLD IRON	2	0.062%	0.168%	0.063%	0.175%
CRUSH	2	0.062%	0.168%	0.063%	0.175%
	1190		100.000%		100.000%

T A B L E 10

HEAT DATE IDENTIFICATION - DYNAMIC TEST BARS

BAR NO.	HEAT NO.	CAST DATE JULIAN	BAR NO.	HEAT NO.	CAST DATE JULIAN
1	6014	130	21	6004	191
2	6014	130	22	6034	102
3	6018	96	23	6031	103
4	6021	188	24	6004	191
5	6021	188	25	6031	103
6	6002	191	26	6031	103
7	6002	191	27	6034	102
8	6002	191	28	6013	100
9	6002	191	29	6033	132
10	6020	188	30	6017	187
11	6004	191	31	6033	132
12	6003	191	32	6034	102
13	6011	130	33	6017	96
14	6003	191	34	6013	130
15	6021	188	35	6019	188
16	6014	130	36	6012	130
17	6018	96	37	6012	130
18	6019	188	38	6020	188
19	6020	188	39	6004	191
20	6012	130	40	6011	130.

TABLE 11

DYNAMIC TEAR ENERGIES AT -60°F. FOR 155MM PROJECTILES

BAR NO.	ENERGY INITIATION FT. - LBS.	ENERGY PROPAGATION FT. - LBS.	TOTAL FT.LBS.	HARDNESS BHN
1	4.99	1.66	6.65	241
2	4.27	2.29	6.56	248
3	1.90	4.09	5.99	269
4	5.71	1.90	7.61	229
5	4.41	1.85	6.26	235
6	4.79	1.72	6.51	248
7	1.91	3.68	5.59	269
8	4.15	1.91	6.06	255
9	1.91	4.35	6.26	255
10	2.10	4.55	6.65	235
11	2.31	3.03	5.34	269
12	2.16	3.64	5.80	255
13	3.91	2.63	6.53	262
14	2.15	4.39	6.54	269
15	5.60	1.82	7.42	255
16	1.56	4.67	6.23	229
17	3.71	2.27	5.99	269
18	2.12	4.35	6.47	255
19	1.78	4.24	6.03	248
20	2.11	4.47	6.59	229
21	1.96	4.79	6.75	248
22	2.08	4.06	6.14	255
23	4.23	2.41	6.64	255
24	1.61	5.02	6.63	255
25	2.16	4.40	6.56	269
26	5.17	2.22	7.38	269
27	1.66	3.91	5.57	241
28	6.04	2.70	8.74	248
29	4.19	2.30	6.50	235
30	2.15	3.53	5.69	262
31	2.32	3.90	6.21	241
32	4.52	2.52	7.04	262
33	1.83	4.84	6.67	269
34	1.71	4.29	6.00	262
35	5.26	1.91	7.17	241
36	4.66	1.76	6.42	241
37	1.52	4.93	6.46	241
38	2.01	4.42	6.43	235
39	2.01	3.87	5.88	262
40	1.80	4.66	6.47	235

LOAD SCALE = 2000   DROP HEIGHT = 1

TABLE 12

CAPABILITY ANALYSIS

FILE NAME: A:\DATA\155MM
No. 1 OF 1 Stats based on 40 subgroups.
DATE: 02-01-1990

Wagner Castings Company
Military
PART NUMBER
155mm Projectile Project
OPERATION
D.T. Lab Results

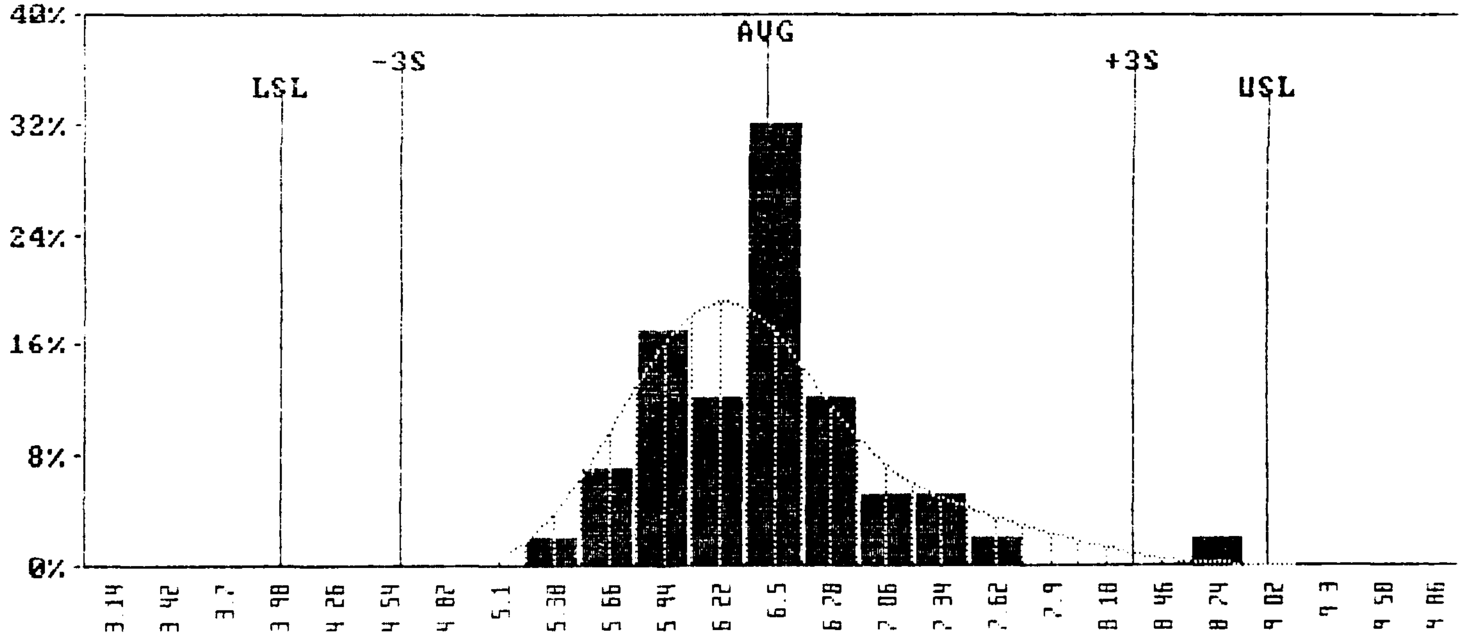
CHARACTERISTIC
Total Foot-Lbs Energy
ENGINEERING SPECIFICATIONS
4.00 TO 9.00 Ft-Lb

COMMENT:

COUNT = 40
AVERAGE = 6.4607
STD.DEV.= .6183
SKEWNESS: 1.204
KURTOSIS: 2.873
3 SIGMA LIMITS = 4.6058 TO 8.3156
4 SIGMA LIMITS = 3.9875 TO 8.9339

DISTRIBUTION TYPE = SKEW RT
CpK = 1.33 CPR = 74.2 % CPI = 1.35
NUMBER OF ACTUAL POINTS OFF SCALE: BELOW = 0 ABOVE = 0
PERCENT OUT OF SPECIFICATION LIMITS:
BELOW LSL = 0 % ABOVE USL = 0 %
Z-TABLE VALUES:
Z-LSL = 3.98 Z-USL = 4.11

HISTOGRAM



T A B L E 13

COMPARISON OF AVERAGE HARDNESS TO AVERAGE D.T. ENERGY

HARDNESS	BHN	TOTAL ENERGY ft - lb
229	4.00	6.81
235	3.95	6.46
241	3.90	6.41
248	3.85	6.46
255	3.80	6.42
262	3.75	6.23
269	3.70	6.20

TABLE 14

DYNAMIC TEAR ENERGIES FOR 155MM PROJECTILE FROM -150°F. TO +150°F.

BAR NO.	TEMPERATURE °F.	ENERGY INITIATION FT.-LBS.	ENERGY PROPAGATION FT.-LBS.	ENERGY TOTAL FT.-LBS.	BHN NO.
1	150	8.9	8.21	17.11	255
2	150	9.02	7.83	16.85	262
3	100	8.24	3.92	12.15	269
4	100	7.38	4.60	11.98	241
5	100	7.86	3.86	11.72	255
6	75	7.39	4.38	11.77	241
7	75	7.67	4.40	12.07	235
8	75	7.78	3.47	11.25	269
9	50	7.15	3.91	11.06	235
10	50	7.02	3.33	10.35	255
11	50	6.98	2.25	9.24	269
12	0	1.79	4.09	5.88	262
13	0	4.46	2.14	6.59	255
14	0	4.30	2.50	6.80	255
15	-60	2.10	4.55	6.65	235
16	-60	3.79	2.65	6.45	269
17	-100	4.46	2.13	6.59	255
18	-100	3.32	2.41	5.73	241
19	-150	2.06	4.16	6.23	229
20	-150	2.39	2.31	4.70	255

LOAD SCALE = 2000 DROP HEIGHT = 1

FIGURES

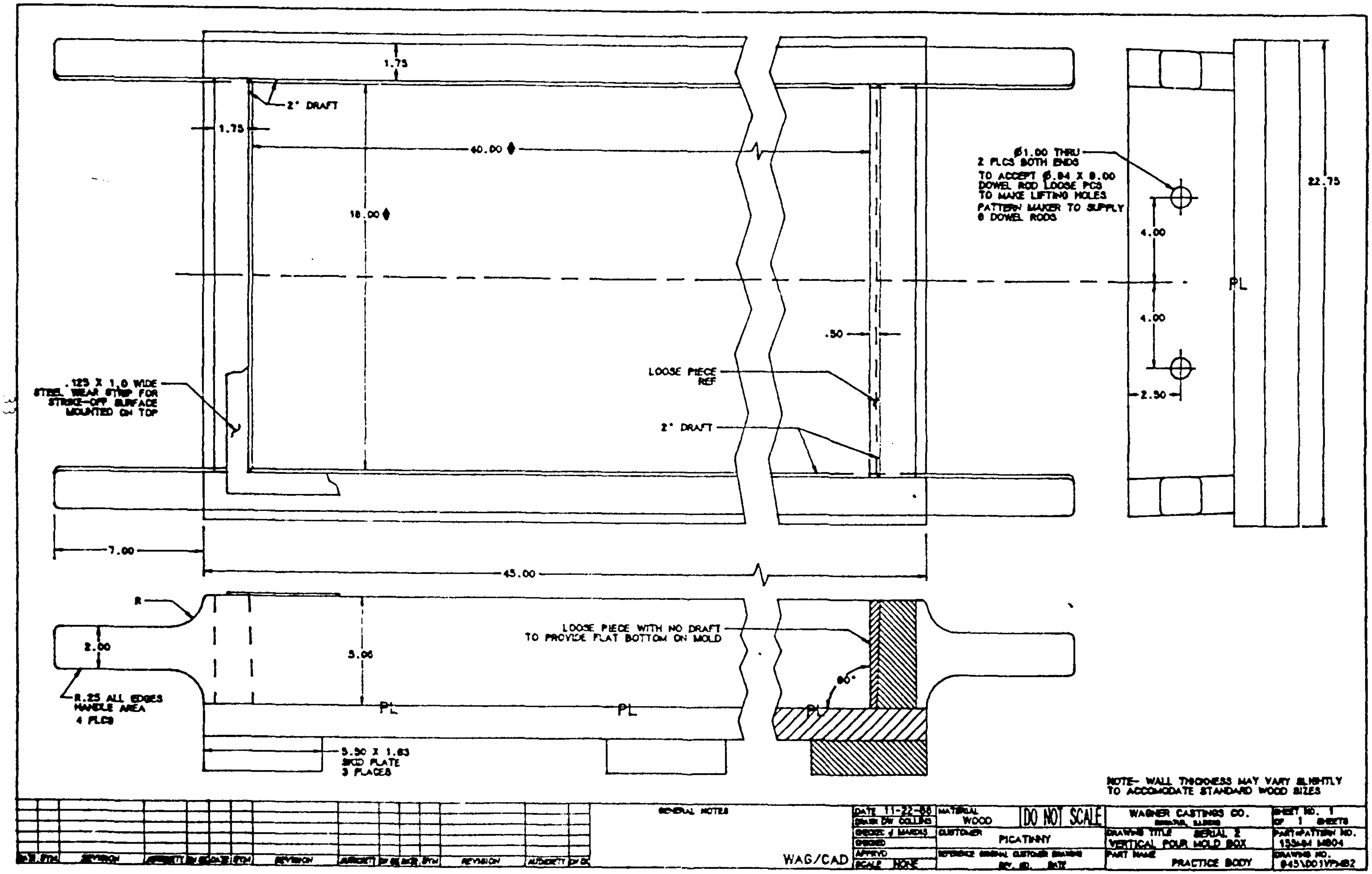


FIGURE 1: VERTICAL MOLD/FLASK

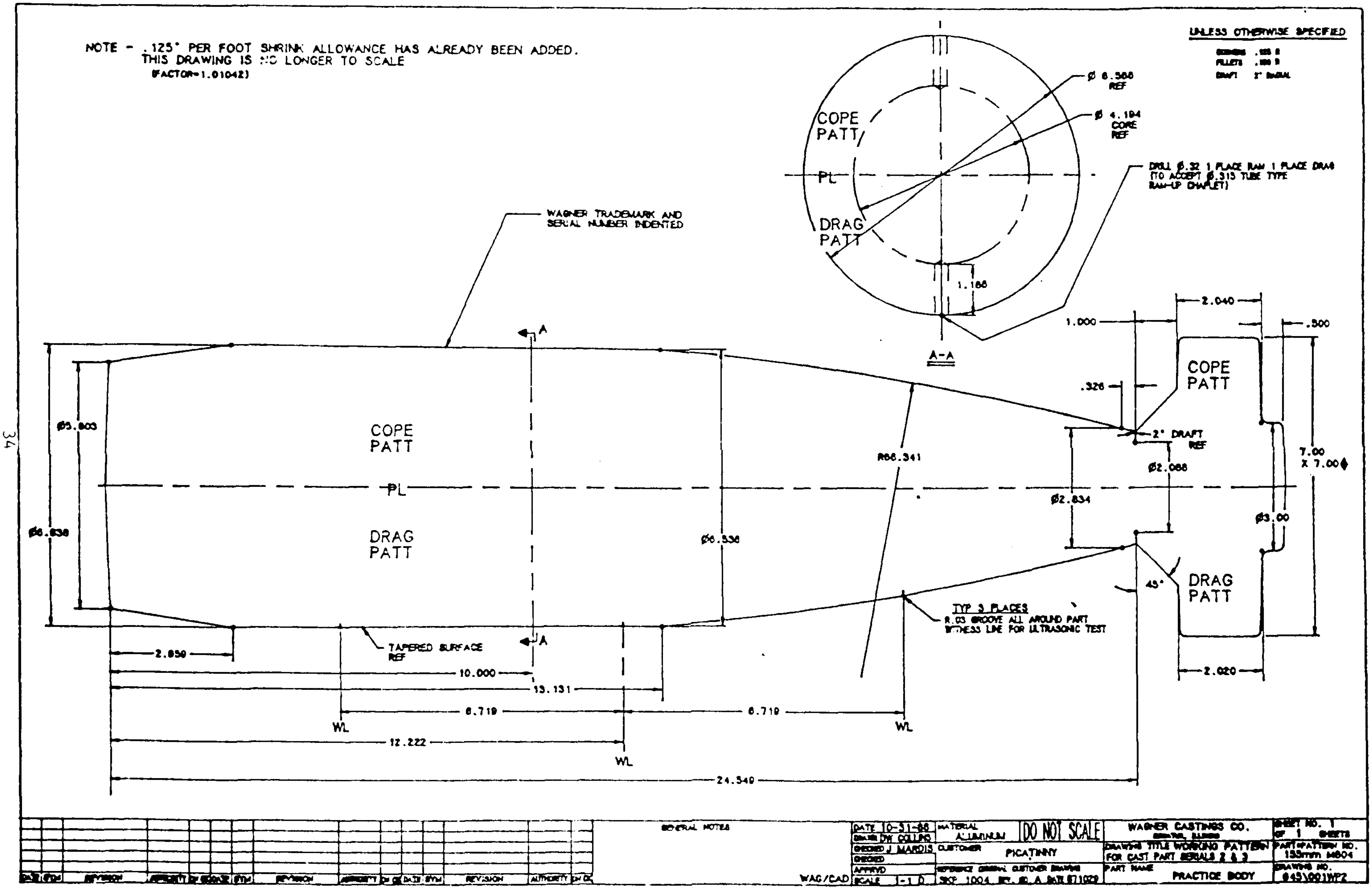


FIGURE 2: WORKING PATTERN

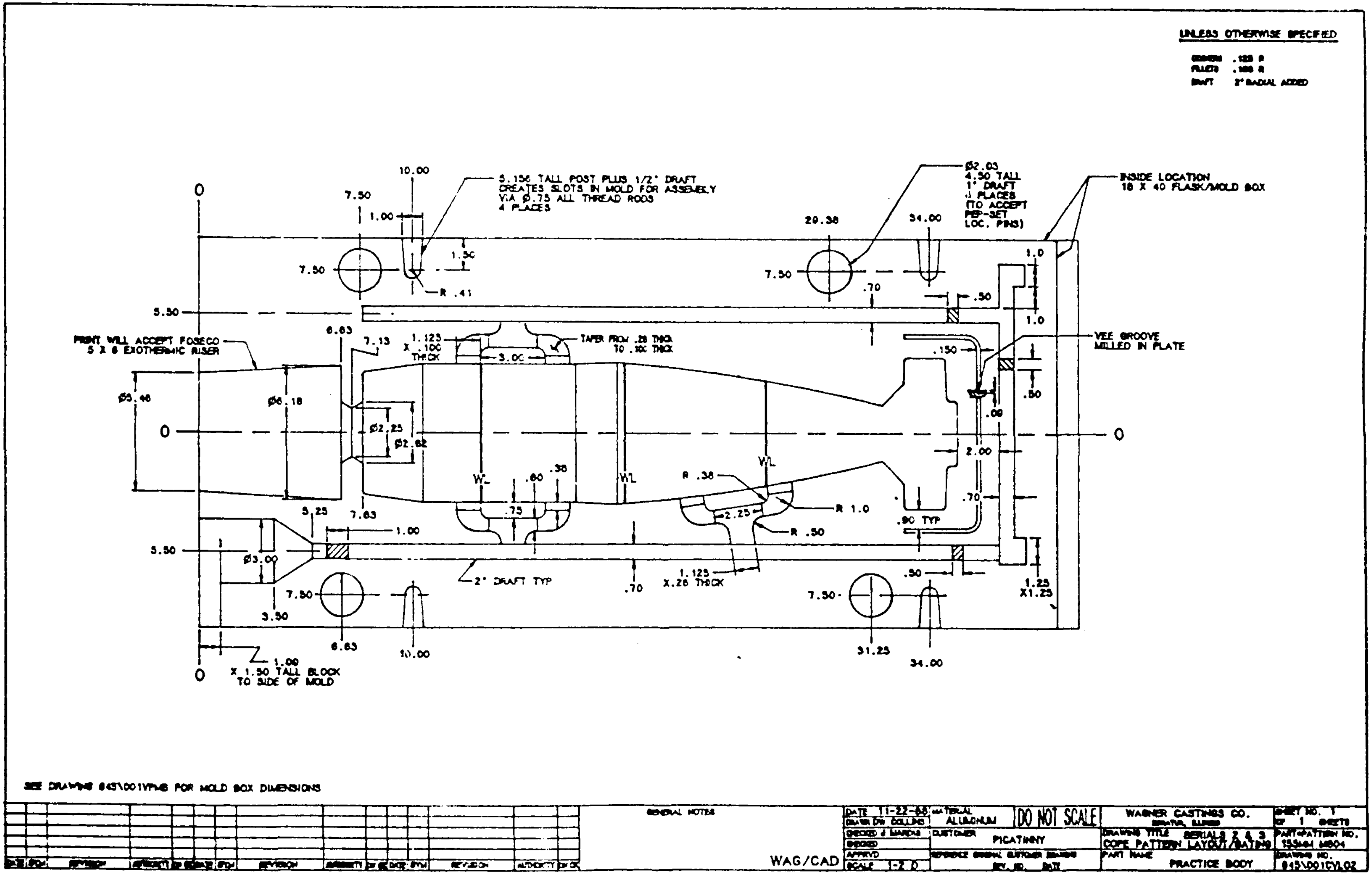


FIGURE 3: VERTICAL MOLD (COPE)

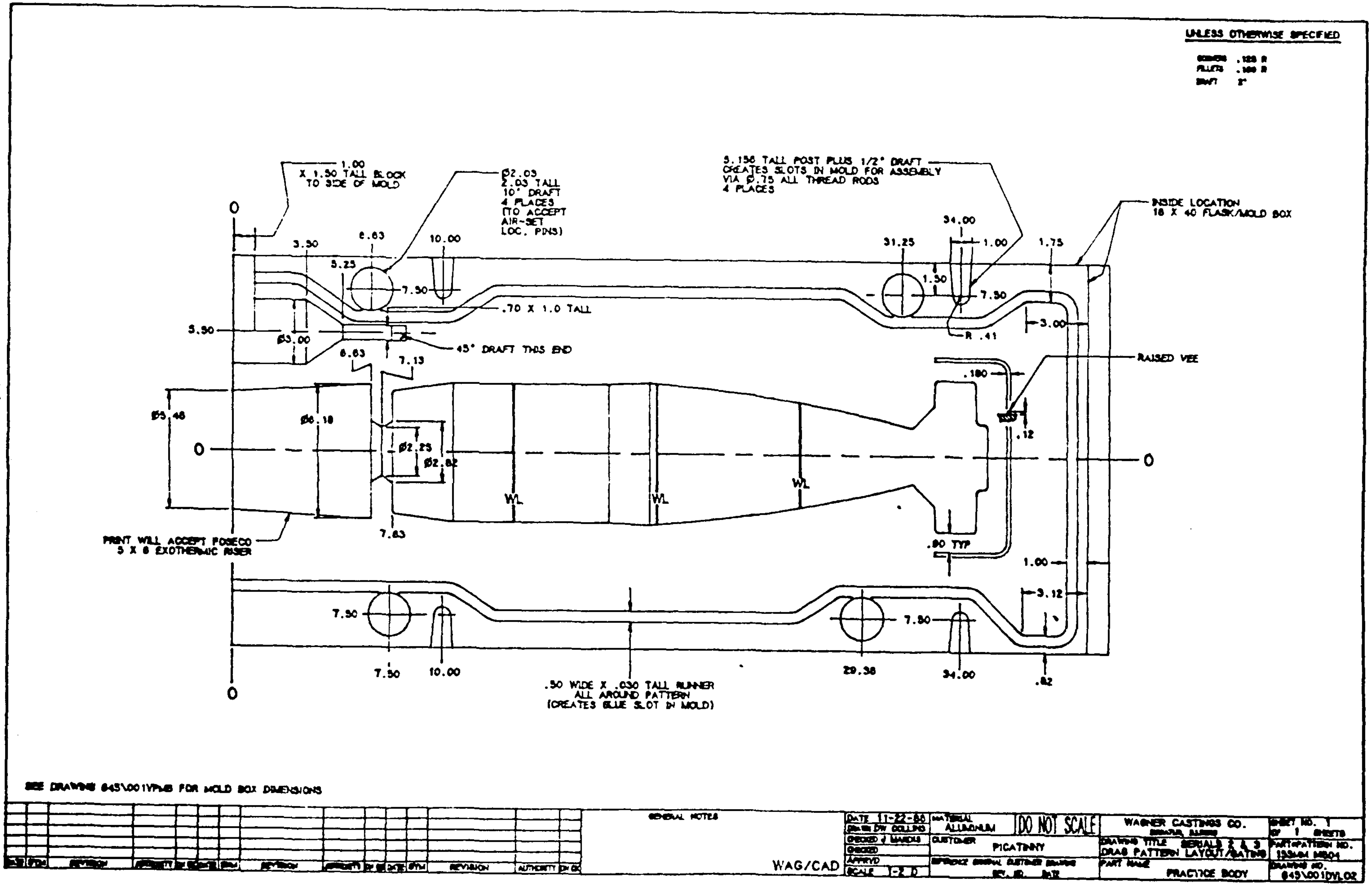


FIGURE 4: VERTICAL MOLD (DRAG)

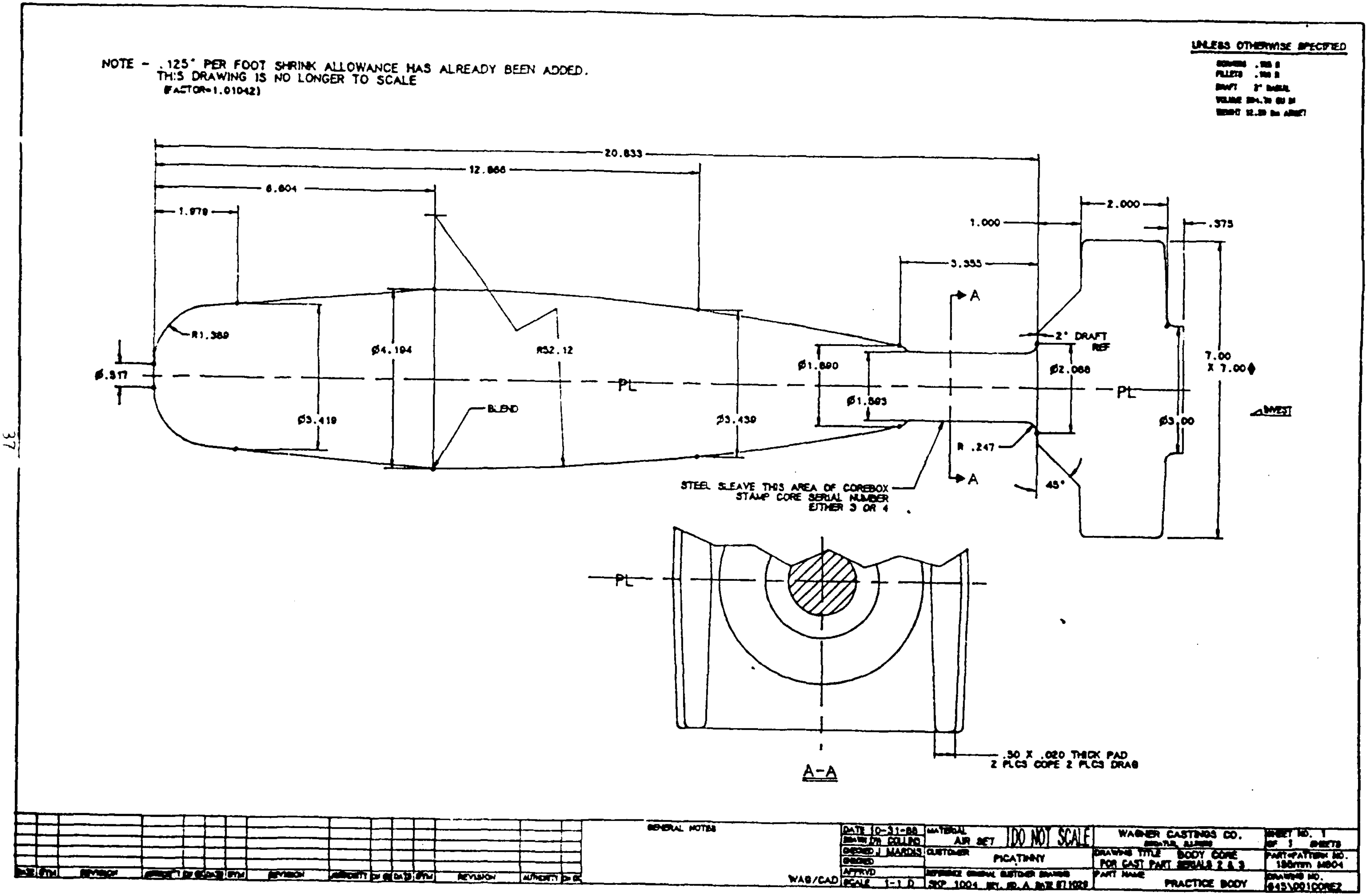


FIGURE 5: CORE BODY

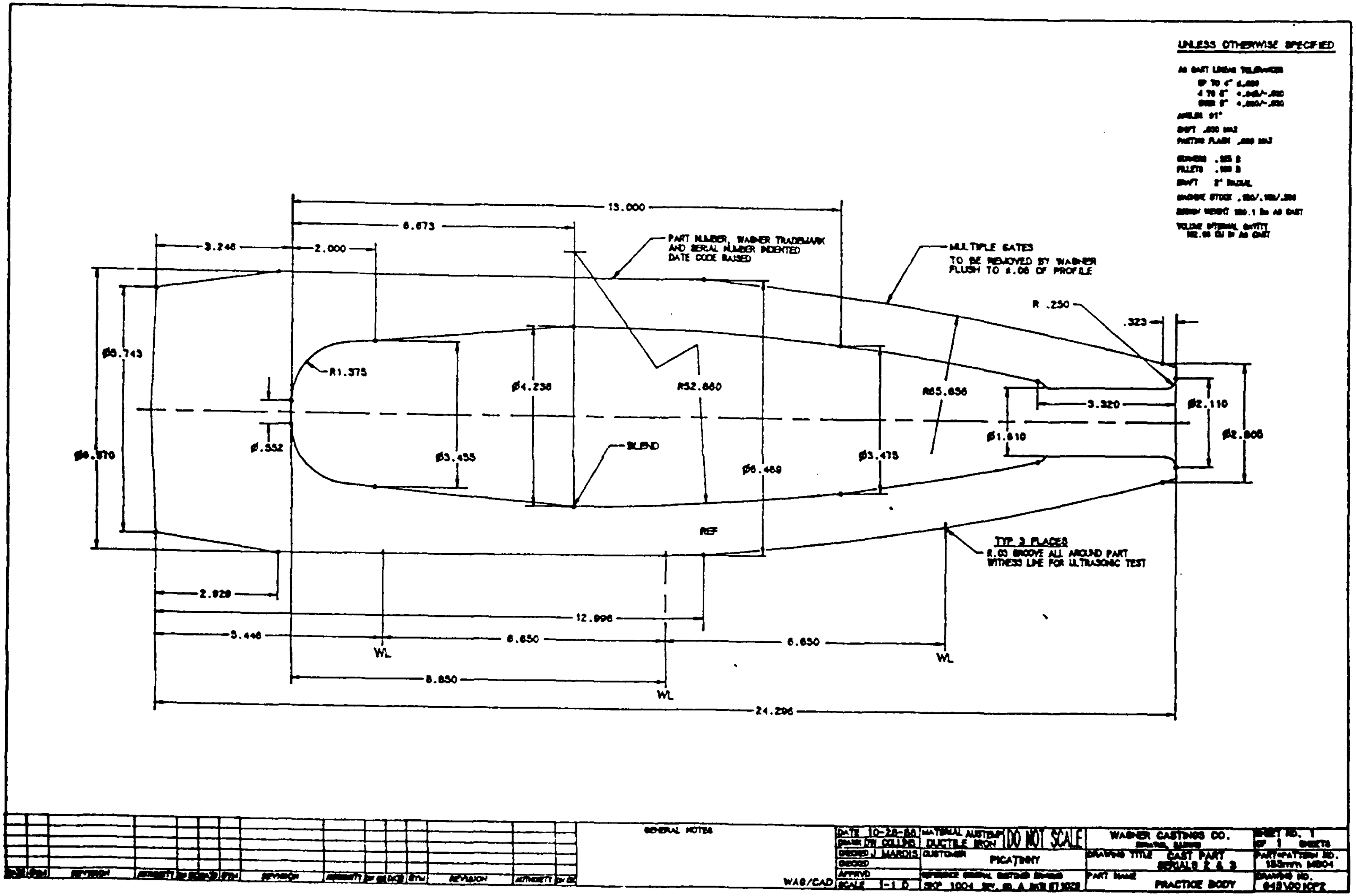


FIGURE 6: CAST PROJECTILE

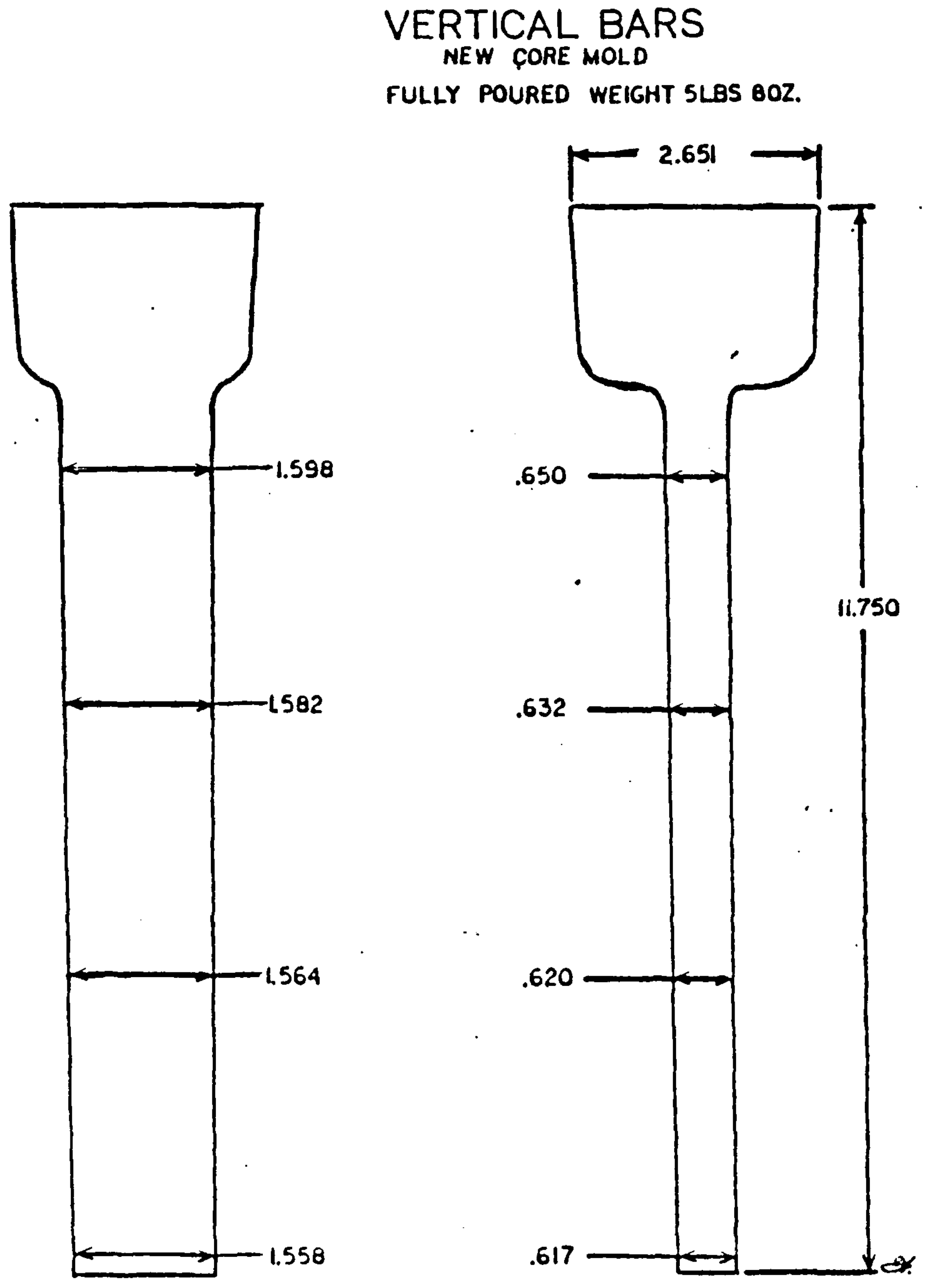
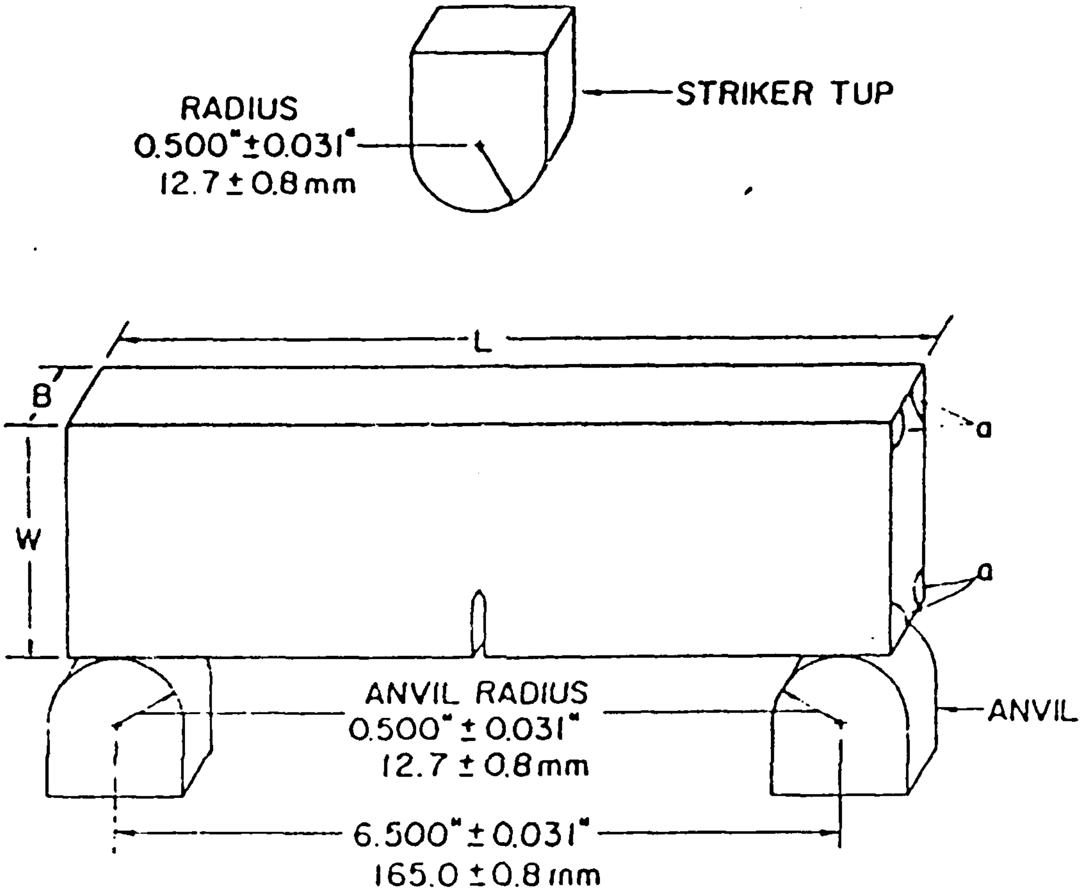


FIGURE 7: Cast vertical dynamic tear bar, dimensions in inches.

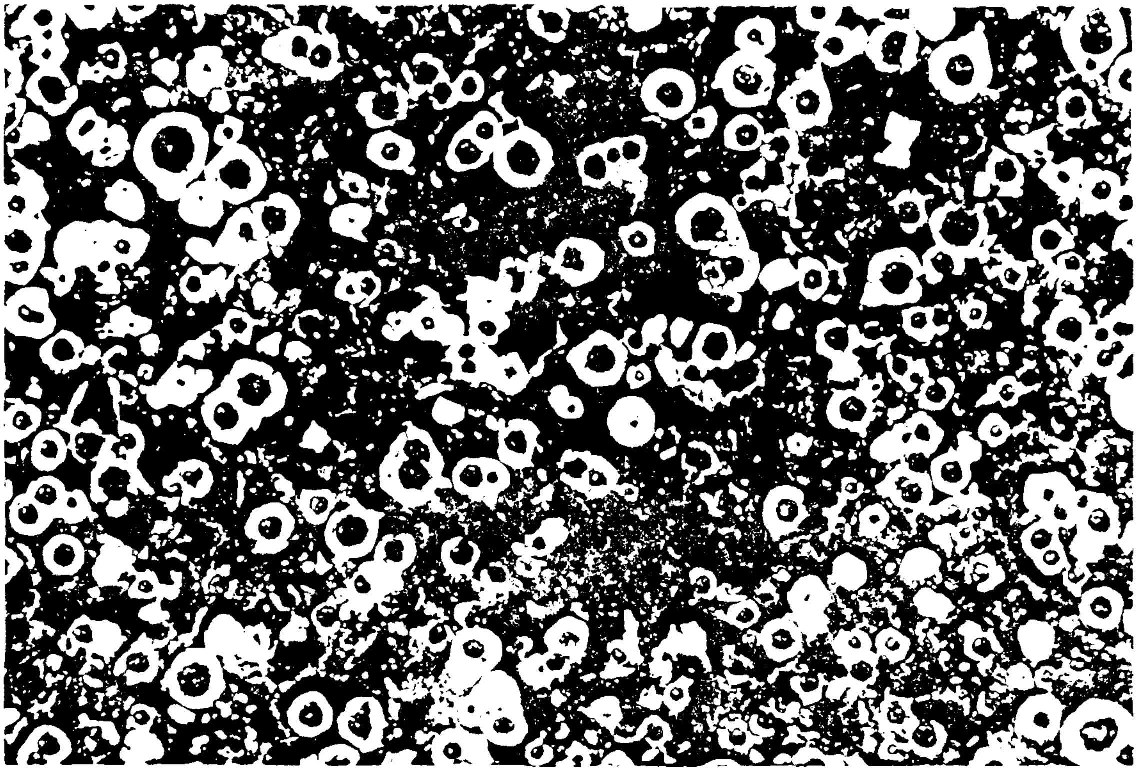


Dimensions and Tolerance for Specimen Blank

Parameter	Units	Dimension	Tolerance
Length, *L*	in.	7.125	±0.125
	mm	181	±3
Width, *W*	in.	1.60	±0.10
	mm	41	±2
Thickness, *B*	in.	0.625	±0.035
	mm	16	±1
Angularity, α	deg	90	±1

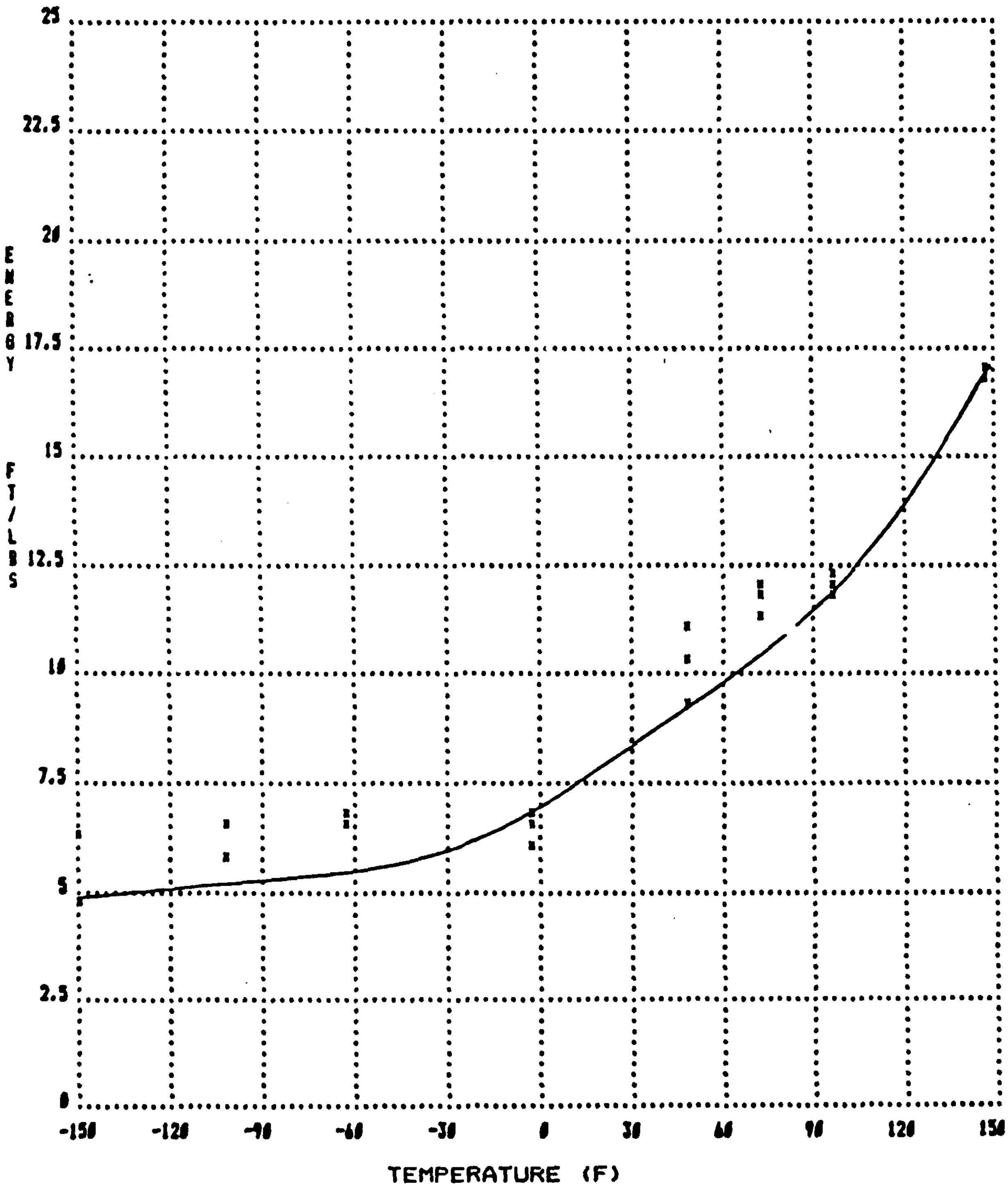
DYNAMIC TEAR IMPACT TEST

FIGURE 8: Dynamic tear bar, machined.



[illegible] Typical microstructure [illegible] of [illegible] projectile, [illegible] [illegible] pearlitic matrix, bullseye type graphite, [illegible] [illegible]

DYNAMIC TEAR ENERGY V.S. TEMPERATURE
155MM FULL RANGE TEMP. TEST



X - 155MM 269-229 BHN

DATE POURED 1989 **FIGURE 10:**

GLOSSARY

Anneal: Generally a heat treatment to soften iron; hold at a critical temperature followed by slow cooling.

Airset: A sand bonding process utilizing phenolic urethane with a catalyst. Produces an extremely hard final product. .

Carbon Equivalent: The carbon percentage plus one third of the silicon percentage. This is tightly monitored because of carbon's effect on shrinkage.

Cope: The upper(1/2) halve portion of a vertical produced mold.

Core print: A segment of the mold which secures a portion of the core and acts as a positive locator during the casting process.

Depenadable Continous Mixer: The mixing machine for the airset method. Basically a large auger fed from a sand tank. The binder chemicals (Part A and B) are fed into the auger, where the mixing occurs, while the catalyst is fed into the paddle mixer at the end of the auger. This machine is rated at 290 lbs per minute mixed. The M804 airset mold weighs approximately 300 lbs assembled.

Drag: The lower (1/2) halve portion of a vertical produced mold.

Dynamic Tear: The measure of the toughness of the material to resist rapid progressive cracking. *ASTM E604-83.*

Exothermic Riser: A reservoir of feed metal made available to the casting during solidification to compensate for liquid and solid contraction. An exothermic riser is one which utilizes a manufactured sleeve that reacts exothermically to keep the feed metal molten longer.

Flask: Simply, a box (four-sided) which contains the sand while the molding process is accomplished.

Nucleation: Creation of sites for graphite nodule formation, both carbon and silicon molecules can function in this capacity. With time the effect of nucleation fades; therefore, there is a need for renucleation by the addition of ferrosilicon and/or graphite.

Sprue: A generic term to cover all gates, risers, etc., returned to melting unit for remelting.

Thermal Analysis: A method of determining transformations in a metal by noting the temperatures at which thermal arrests occur.

Tucking: Process of selective compaction using a special foundry shovel with a blade-shaped handle to pinch the sand around critical areas.

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